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Core Protection Method with 4-Channel CEA Signals for Application of OPR-1000 Plants

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1. Introduction

In digital protected nuclear power plants, Core Protection Calculator System (CPCS) is used for a core protection based on several online measured system parameters. The CPCS provides four independent channels for the departure from a nucleate boiling ratio (DNBR) and local power density (LPD) trip signals to the reactor protection system [1]. Each channel consists of a Core Protection Calculator (CPC) and a Control Element Assembly Calculator (CEAC). This system has been used in OPR-1000 plants in Korea and it is reported that several abnormal trip generations have been caused by a transmission of improper penalty factors and by a failure of CEA related hardware [2].

The Korea Atomic Energy Research Institute (KAERI) has been developing a system-integrated modular advanced reactor (SMART) with an on-line digital core protection system for a seawater desalination and electricity generation [3].

To overcome the generation of abnormal trips in a conventional CPCS and increase the applicability of research results established during the process of an integral reactor development, a new core protection method with 4-channel CEA positions was suggested and its feasibility was evaluated. In addition, this paper describes the state-of-the-art related to a core protection system in various countries.

2. Core Protection Method

2.1 Conventional Core Protection System

In a conventional core protection, each CEAC receives all of the analog CEA positions which come from one of two Reed Switch Position Transmitters (RSPT) associated with each CEA and calculates the CEA deviation penalty factors based on the magnitude of a CEA deviation within a subgroup. These two penalty factors are transmitted to four CPCs and then each CPC performs the protection algorithm with measured input signals and CEA deviation penalty factors. In other words, the CPCS is composed of 2 functional parts (CPC and CEAC). A CPC calculates the DNBR and LPD to initiate a reactor trip and a CEAC continuously measures the positions of all the individual CEAs to detect deviations and provides penalty factors. This unmatched functional structure (4-CPC/2-CEAC) is the primary reason for the generation of undesirable trip by a transmission of improper penalty factors and by a failure of CEA related hardware.

Recently, Westinghouse has developed the Common-Q CPC system to alleviate the problems occurred in conventional CPCS [4]. In this system, another CEAC with CEA Position Processor (CPP) is introduced, i.e., two CEAC and two CPP per each channel. A CPP shall receive each analog CEA position measurement signals which originate from one of two RSPTs associated with each CEA. In spite of a hardware improvement, it is expected that the generation of an undesirable trip due to a signal transfer won't be decreased. Even more, possibility of a hardware failure and the burden of maintenance shall be increased.

2.2 Aeroball and PDD Core Protection System

The core power surveillance of Siemens pressurized water reactors combines two complementary in-core instrumentation systems, i.e., Aeroball system and Power Density Detector (PDD) system [5]. Aeroball system is a movable flux mapping system and PDD system continuously monitors the core using fixed in-core prompt responding detectors. The calibration process functionally links the two systems, the monitoring signals being calibrated at regular intervals against data from Aeroball system.

The ex-core detector system is used for surveillance and limitation of the integral reactor power and provides information about global axial or azimuthal power shapes. The system relies on neutron flux signals of the out-of-core (ex-core) instrumentation and on loop temperature increases. Figure 1 shows the combined in-core Aeroball and PDD systems.

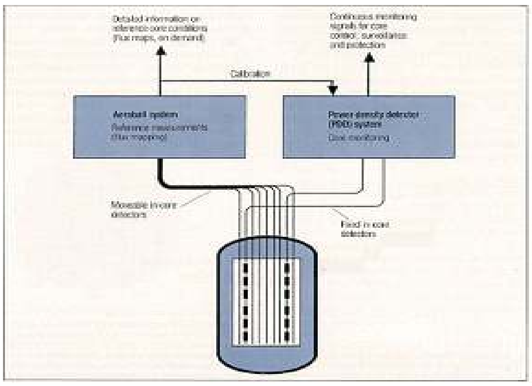

Figure 1. Combined in-core Aeroball and PDD systems.

2.3 SENTINEL Core Protection System

SENTINEL core protection system is a safety grade protection system for monitoring parameters indicative of the status of a core of a nuclear reactor, and reducing the criticality of a nuclear plant when the onset of unsafe conditions are detected [6]. The system directly detects the power at a plurality of axial and radial locations within the core and provides a 3-D real-time core power. The system processes those outputs together with a measure of the core coolant inlet temperature, pressure and flow rate to calculate the fuel centerline temperature, heat transfer condition at the fuel elements' boundary and the rate of a power change within the core.

SENTINEL protection system is realized by introducing a hybrid fixed in-core detector which is composed of a neutron sensitive Vanadium emitter and a number of gamma sensitive Platinum emitters. Platinum detector generates prompt responding gamma signals without a time-delay and a Vanadium detector is used to calibrate the prompt signals. Figure 2 shows the functional diagram of the SENTINEL core protection system.

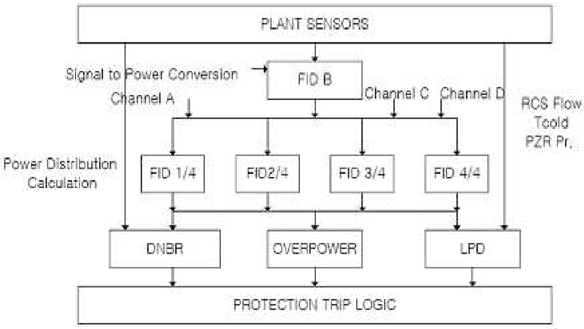

Figure 2. Functional diagram of SENTINEL core protection system.

2.4 Core Protection System with 4-Ch. CEA Signal

Newly designed core protection system with 4-channel CEA positions was suggested [7]. This system simplified its structure by eliminating the CEAC hardware and by directly connecting four RSPT signals to each core protection channel. The elimination of the CEAC was achieved by using a new CEA position indicator which has four RSPT instead of 2 RSPT per each CEA [8].

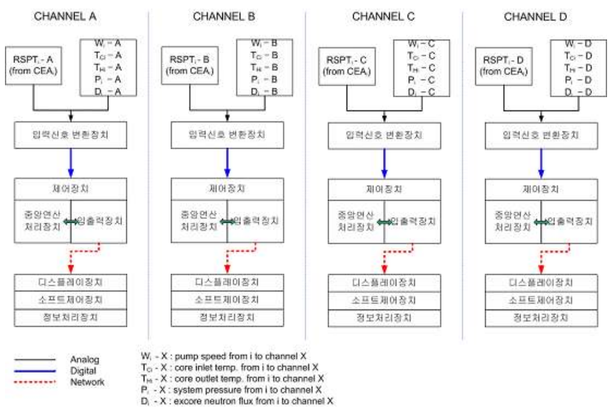

Figure 3. Configuration of core protection system with 4-channel CEA signals.

As shown in Figure 3, every channel receives independent signals including the CEA position signal and calculates the DNBR and LPD trip parameters. By eliminating the CEAC, possibility for the occurrence of an undesirable trip induced by a transmission of improper penalty factors is removed. In addition, several functional algorithms (module structure, trip alarm, monitoring parameters and so on) were considered and the sensor validation process was upgraded in this system. As a result, it is expected that unnecessary channel or reactor trips will be decreased considerably by adopting this method.

4. Conclusions

A new core protection method with 4-channel CEA positions was suggested for the OPR-1000 digital protected nuclear power plants and its feasibility was evaluated. By adopting this method, it is expected that unnecessary channel or reactor trips will be decreased considerably.

Although a change of the system including a CEA must be set forth as a prerequisite to apply this method to the OPR-1000 plants, this study suggests the strategy and direction for the development of a core protection system in the domestic arena. This study, moreover, provides valuable information as basic data for establishing a detailed development plan for an advanced core protection system in the future.

Acknowledgements

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